NOvA APD Cooling Water Update

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APD/TE Heat Load & Water Flow

Assuming 5 watt (J/sec) max heat production per APD module and ignoring any heat pickup from outside module structure:

mass/second = (Q/sec) / (spec heat x delta T)

= (5 J/sec) / (4.186 x 1)

= 1.19 gram/sec = 1.19 cc/sec

Experiments at Indiana indicate that about 2 cc/sec is the real-world number.

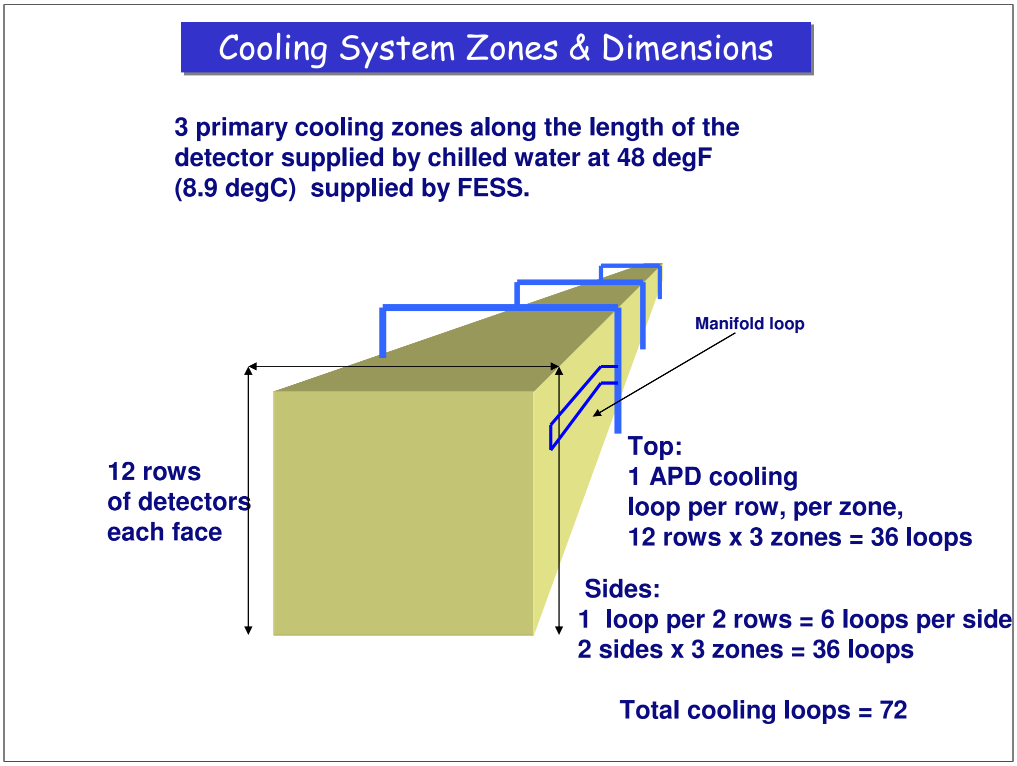
2 cc = 0.002 L/sec x(0.2642 L/gal) = 5.28 e - 4 gal/sec

= 0.0317 GPM (gal/minute) per APD module

Total Heat Load

Heat load from APD/TE Modules = 16368 x 5 watts	= 82kW
Heat load from distribution system (guesstimate)	+ 82kW
Total	= 164kW
	= 38 tons refrigeration

We are assuming that the heat picked up from the environment in the process of circulating all this water in finely divided streams will probably equal that from the APD/TE cooler modules themselves, even with insulation. So we may need more than the 30 ton chiller capacity figure that has been used in conversation up to now.



Subject to change as detector morphs to new sizes & shapes. The figures in this presentation are based on 20 kiloton dimensions.

Manifold loops supplying water to APDs will run in ~ 1meter spaces between rows of APD boxes.

Good news is that this system is SCALEABLE

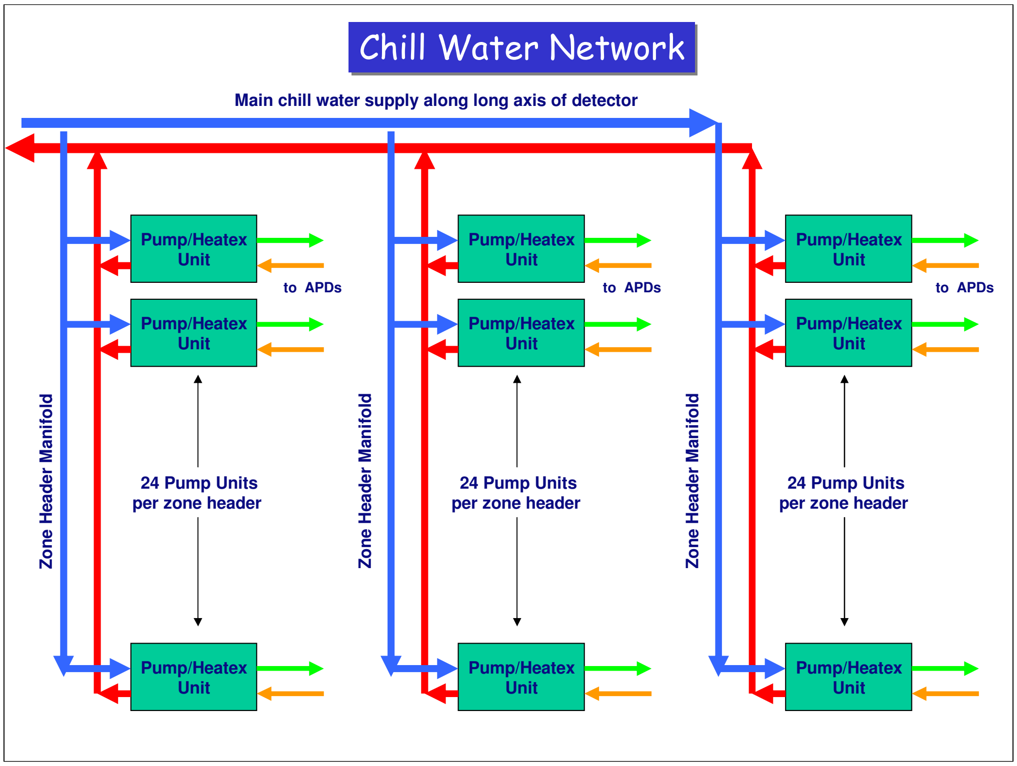
Once dimensions stabilize, changes in heat load can be met by changing components that don't have major impact on total cost.

Two Major changes from last concept:

*chill water zones reduced from 4 to 3

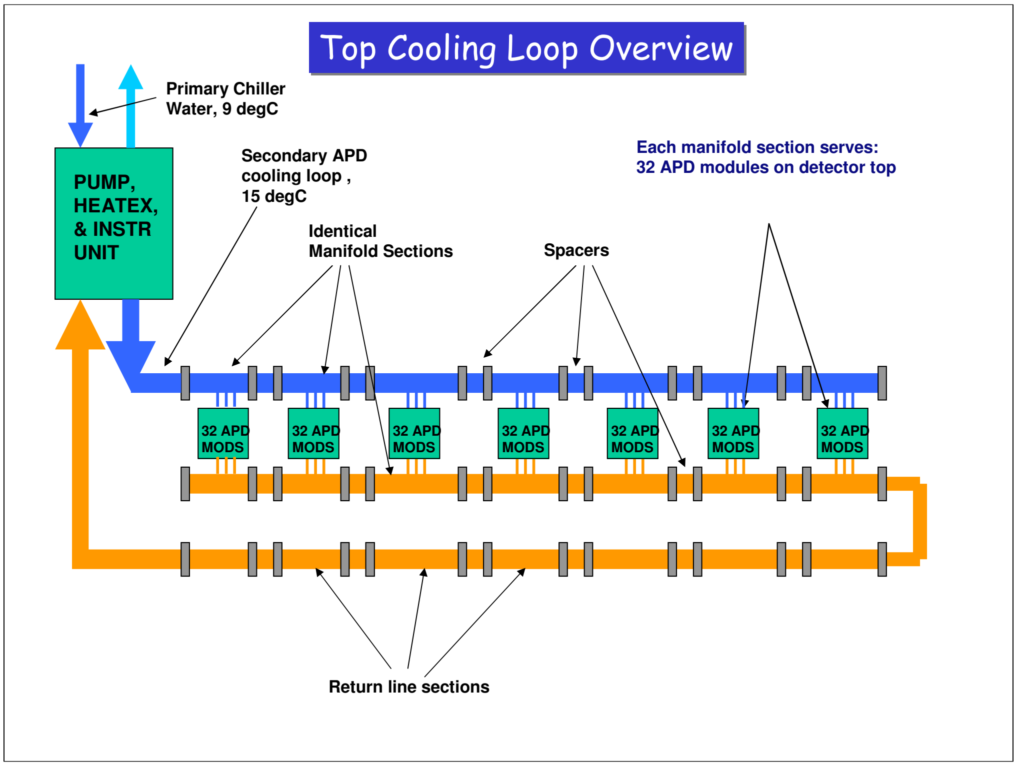
*doubled loop length on sides, resulting in half number of loops & pump units needed there.

*total resulting number of pump units cut by half from 144



This should help get the idea across. The system is divided into small loops running horizontally along rows of detectors in the long axis of the detector. This means the manifolds feeding the APD hose connections can be run with, or at least parallel to the cable trays. The use of heat exchangers isolates each loop from the static fluid head resulting from the height of the detector, which will be about 25 PSI at the lowest points in the primary chill water feed system. This limits the amount available to leak from any loop to about 20 gallons maximum, make early leak detection possible, and once the pump is shut off, there will be very little pressure to drive the leak.

It also means that complicated three dimensional pipefitting for the up & over headers only has to be done three times along the length of the detector, not for each of the 22 dual block sections.



Each loop is a closed system isolated from main chill water supply by heat exchanger.

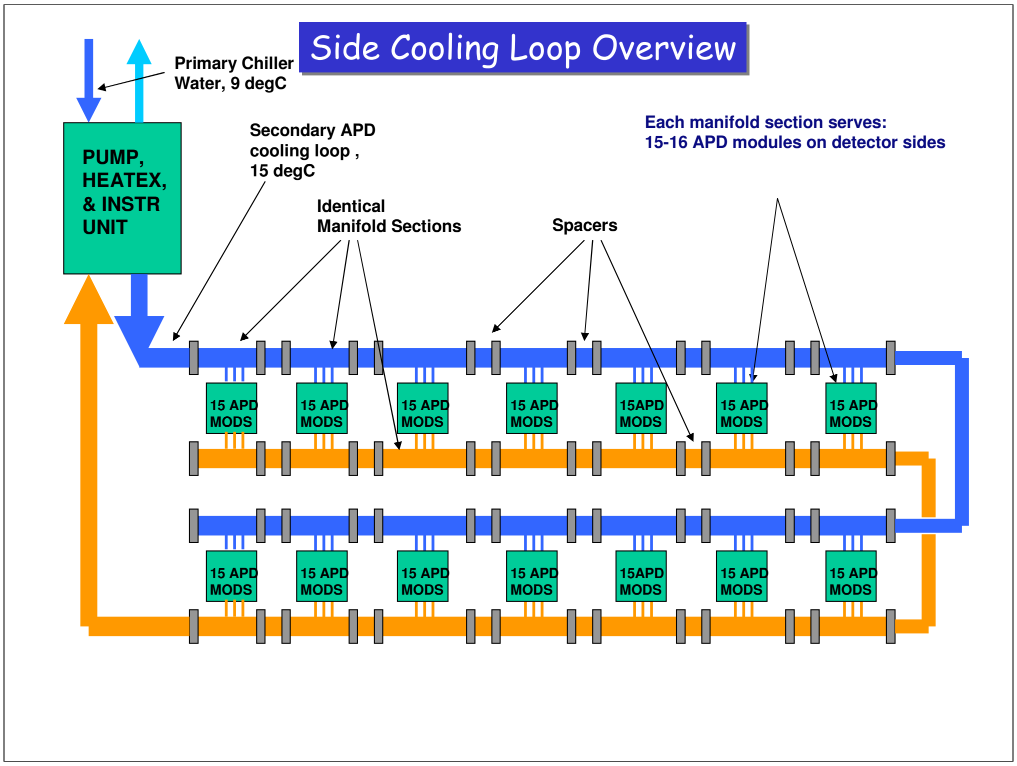
Each loop starts at a unit containing the pump, heat exchanger, fluid reservoir, and remote I/O(more in later slide)

Water is delivered to APDs by 1/4'' hoses connected to modular manifold units used in both supply and return side of loop.

Water comes back in return line sections of same length as manifolds.

Manifold sections are designed to serve two blocks(62 planes), so that cooling system can be assembled and run incrementally as detector is built up if necessary.

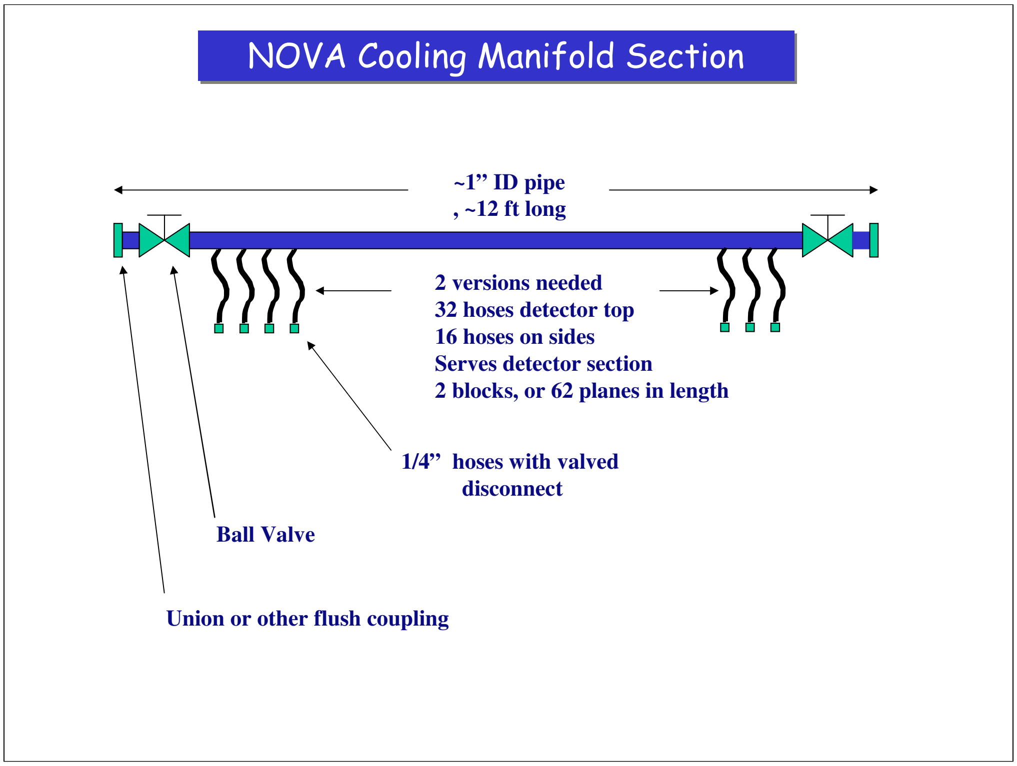
For 20 kton detector, with 22 double blocks of 62 planes, there would be 2 zones with loops 7 manifold sections long, and 1 zone of loops 8 manifold sections long.



Since APD density is half that of rows on detector top, Loop length has been doubled to serve two rows.

Each pump unit, top or side, now serves about the same number of APD modules with approximately the same heat load and flow requirements.

Also eliminates need for separate return lines used on detector top loops.



Modular manifolds keep length in easy to ship range, which is important, since we want to have these contract manufactured.

Exact number of hoses(planes) needed is in flux. Since quick disconnect fittings are valved, unused hoses really aren't a problem, we just need to make sure there are enough. A hose plus or minus doesn't affect cost much.

Two versions of manifolds needed, 1 for detector top with about 30 hose taps, 1 for detector sides with about half that number.

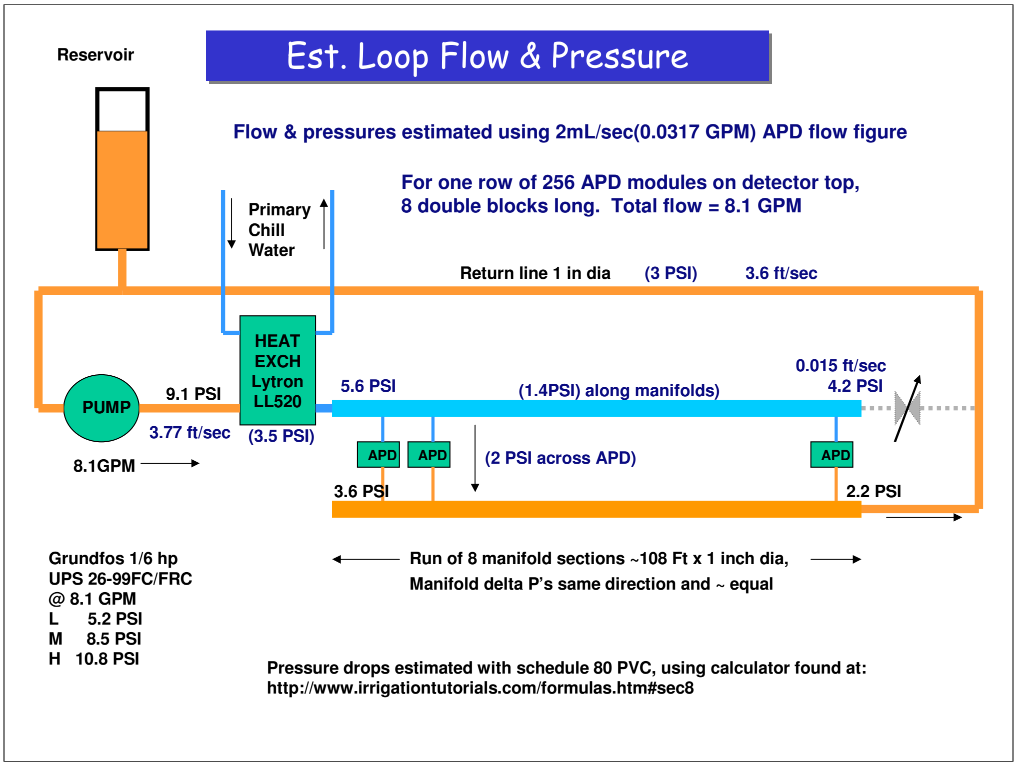
Before downsizing this was 32/16. and we received estimates from two different suppliers with different construction materials & methods. Small variations in actual number of taps will not affect cost.

Both manufacturers were close to same cost. For the 32 tap manifolds about $780, 16 tap $580, including insulation.

Descriptions: 1) Georg Fischer, big industrial process piping supplier, using HD polyethylene pipe with hose fittings welded(ultrasonically?) in to manifold, using true union ball valves between coupling on ends. Good idea, since manifold can be disconnected on either side of valve, only one valve is needed between each section.

2) Tiger Tech, smaller hose product distributor and custom manufacturer. They would build from PVC pipe, drilled & tapped for 1/8" NPT metal hose barbs, with crimped hose attachments. they propose standard PVC ball valves on ends, with rubber sleeve & clamp couplings used to join sections.

Both suppliers have said anything smaller than 1 inch pipe would make these difficult to manufacture.



This is a reverse return manifold system showing estimated pressures using the 2 ml/sec flow figure from Indiana

Pressure (drops) are in parentheses.

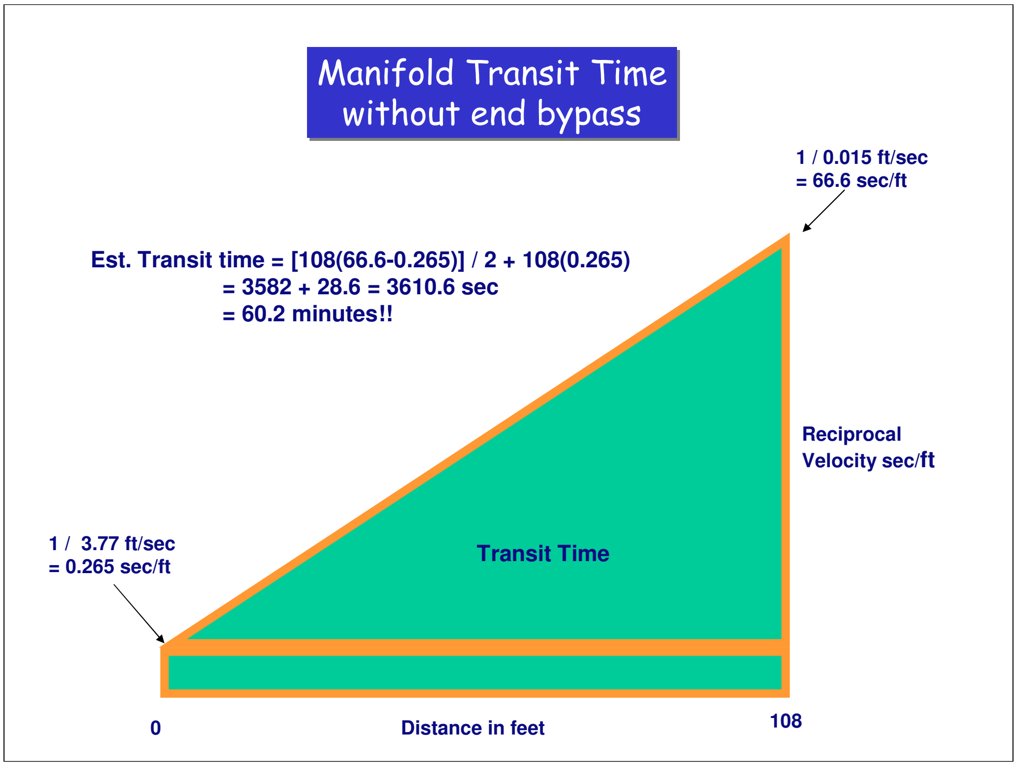
Manifold delta P is from web friction calculator using 1/2 flow rate as average across length

APD modules need to develop necessary flow at some nominal higher pressure to prevent small pressure variations from unbalancing APD flow dramatically. We have suggested 2psi .

Pump is a 1/6 hp version of 3 speed Grundfos Suoerbrute running at high power(curves & data on later slide)

Supply bypass leg shown in gray may be needed to maintain supply manifold temperature uniformity(not sure)

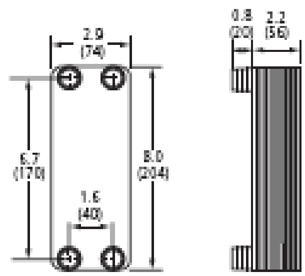
These are rough estimates only. See info on computational modeling software on Macroflow slide.

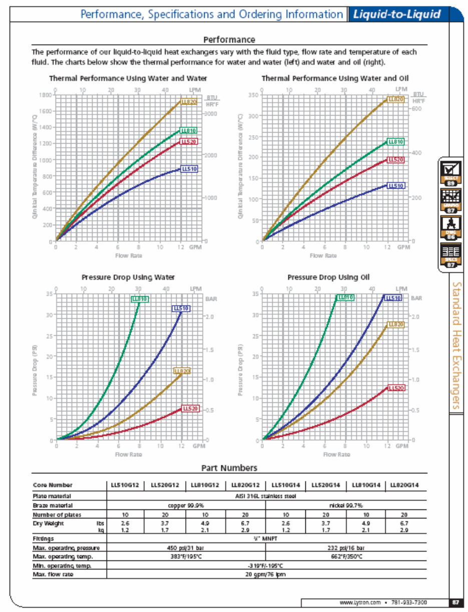


Unless there is some effect to offset this, it looks like we will need the end bypass to keep the water moving, even with good insulation.

Also may need to go back to four primary chill water zone headers, Making the loops shorter. This will add another 24 loops and their pump units, for a total of 108

Why Heat Exchangers?





Why use Heat exchangers?

*Limits fluid available for a given leak to contents of one loop, about 13 gallons.

*Allows leak detection by remote monitoring of fluid level in loop reservoir.

*Localization of detected leaks to ~450 hoses along ~100 feet of manifolds, instead of 40,176 hoses along 14,400 feet of manifolds

*Isolates loop from fluid head due to height of detector, which would be about 22 psi near floor.

*Contains air bubbles introduced due to maintenance or leakage. Imagine trying to bleed the brakes on a car with 20,000 calipers.

Model shown is Lytron LL520

Have been using this unit as our example, because Lytron has so much published data available.

Tranter, suggested by FES, makes a welded stainless unit, but they are about 5x $200 price tag of this LL520. We can keep it in mind. Lytron suggests a nickel brazed option for de-ionized water.

Single Loop Heat Calculations

5w per APD module x 256 units = 1280w
Assume (guess) heat pickup in pipes, etc = 1280w
Total = 2560w

Loop delta T = Q(watts) / [263 x Flow(GPM)]
= 2560w / [263 x 8.1 GPM]
= 1.2 degC

ITD = initial temp difference of fluids entering heat exchanger
= (APD water + del T) - FESS chilled water
= (15 degC + 1.2deg C) - 8.9 degC = 7.3 deg C

Q / ITD for this flow & load = 2560w / 7.3 degC = 350

Compared to high limit value, 900, from Lytron chart for this flow rate, 350 is much lower, so this is well within capacity of LL520

I this slide we perform a heat load calculation for our largest loop size, and check to see if it is in the range of the selected heat exchanger.

Formula for loop delta T is modified version of specific heat formula, Q = cm(dT).

Time units in top and bottom cancel out, units converted for input of watts and water GPM.

It appears that our total heat load could increase substantially and still be OK.

Since delta T, and thus bottom term ITD, increases along with heat load, Q/ITD rises slower than one might think.

Component Volumes

Pipes:

Using schedule 80 PVC pipe, nominal 1" dia,
Actual I.D. = 0.936 in, O.D. = 1.315 in
Pipe Volume = 8.26 in^3 per linear foot

Hoses & APD:

Using 0.25 in I.D. tubing, tube volume = 0.59 in^3 per linear foot
Assuming 3 ft per APD module, tube volume = 1.77 in^3 per APD
Assume 1 in^3 interior volume per APD module,
Total volume of 1 APD module & hoses = 2.8 in^3

Pump Unit:

4" dia x 12" reservoir	150
LL520 heat exchanger	28
pump(guess)	30
10ft pipe	80
	unit total 288 in^3

These figures will be used in weight and thermal expansion calculations

Loop Volumes

APDs & manifolds on detector top:

3 pipes x 13.4 ft x 8.26 in^3 per foot	332
+ (32 x 3 in^3 per APD module)	+ 96
1 loop pipes & APDs for 2block section	= 428 in^3
For loop 8 double blocks long, 8 x 428	3424
+Pump unit volume	+ 288
volume of 1 top loop	= 3712 in^3

APDs & manifolds on detector sides:

4 pipes x 13.4 ft x 8.26 in^3 per foot	443
+ (30 x 3 in^3 per APD module)	+ 90
1 loop pipes & APDs for 2block section	= 533 in^3
For loop 8 double blocks long, 8 x 533	4264
+ pump unit volume	+ 288
Volume of 1 side loop	=4552 in^3

The idea here is to calculate the volume of the manifold/return pipe and APD module combinations per loop. per double block detector section (1 manifold & spacer unit length).

This makes for convenient use in calculations for loops of varying in 2 block units, and weight per 2 block unit.

Estimated Manifold Weights

Pipes:

Sched 80 1in pipe weight,	0.424 lb/ft
water @ 0.0361 lb/in^3 x 8.26 in^3/ft	+0.298 lb/ft
1in pipe & water	=0.722 lb/ft

Hoses, disconnects, & water:

2 x 1.5 ft hose & disconnects for each APD module, assume	0.5 lb

Top manifolds(wet):

3 pipes x 13.4ft x 0.722 lb/ft	29 lb
32 APD modules x 0.5 lb	16 lb
Top supply/return assembly	= 45 lb, or 3.36 lb/ft tray load

Side manifolds(wet):

2 pipes x 13.4ft x 0.722 lb/ft	20 lb
15 APD modules x 0.5 lb	7.5 lb
Side supply return assembly	= 27.5 lb, or 2 lb/ft tray load

Hose &

Cooling Weight per Grating Section

Top loops:
12 APD rows x 45 lb per supply/return assembly 540 lb

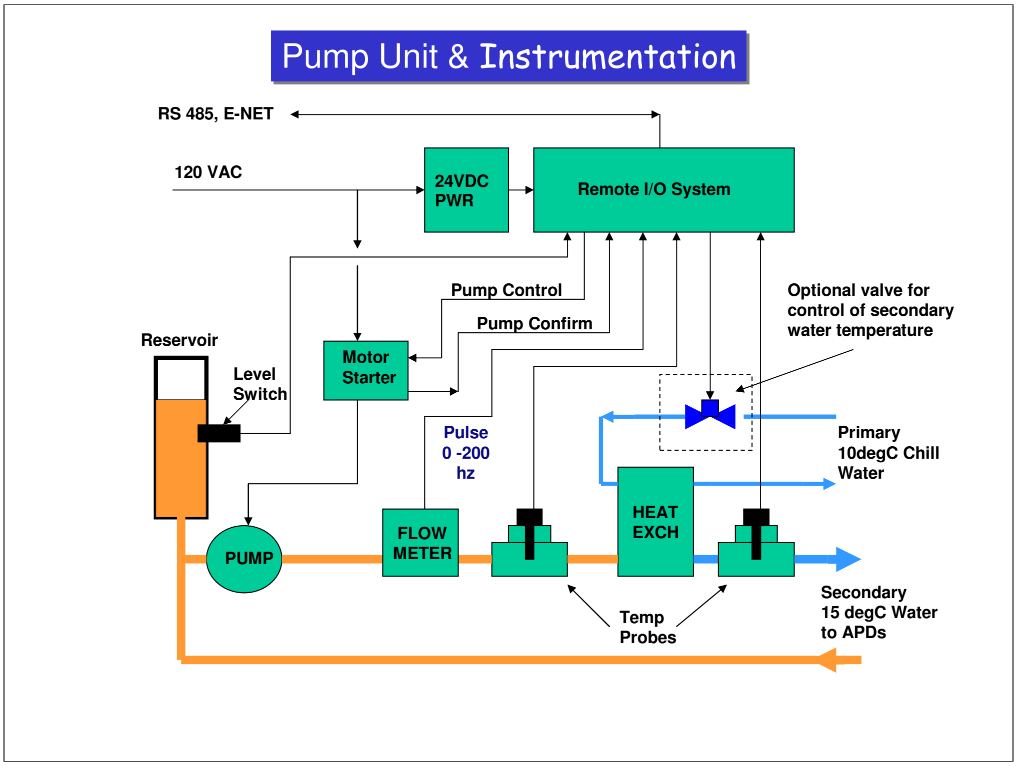
Side loops:
24 APD rows x 27.5 lb per supply/return assembly + 660 lb

Total wet pipe & hose weight per section = 1200 lb

Additional weight at chilled water zone headers:
24 loops x 75 lb per pump unit = 1800 lb

Support gratings will be hung from roof trusses and lowered for use as double block detector sections are raised.

Previous calculations are now combined to estimate loading per support grating section.



More detail on pump unit, showing instrumentation.

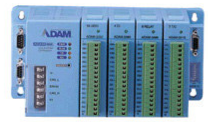
Remote I/O subsystems are available from several vendors, National Instruments, Advantech, Acromag, Opto 22, etc.

Advantech's ADAM series looks promising, with an OPC server available. Should allow easy integration with commercially available HMI/SCADA software such as NI Lookout, Wonderware, etc. This needs thorough research. Caveat emptor.

We have used NI Lookout in a small monitoring system for 5 years now, and it has performed well. See last slides for some screenshots from that system.

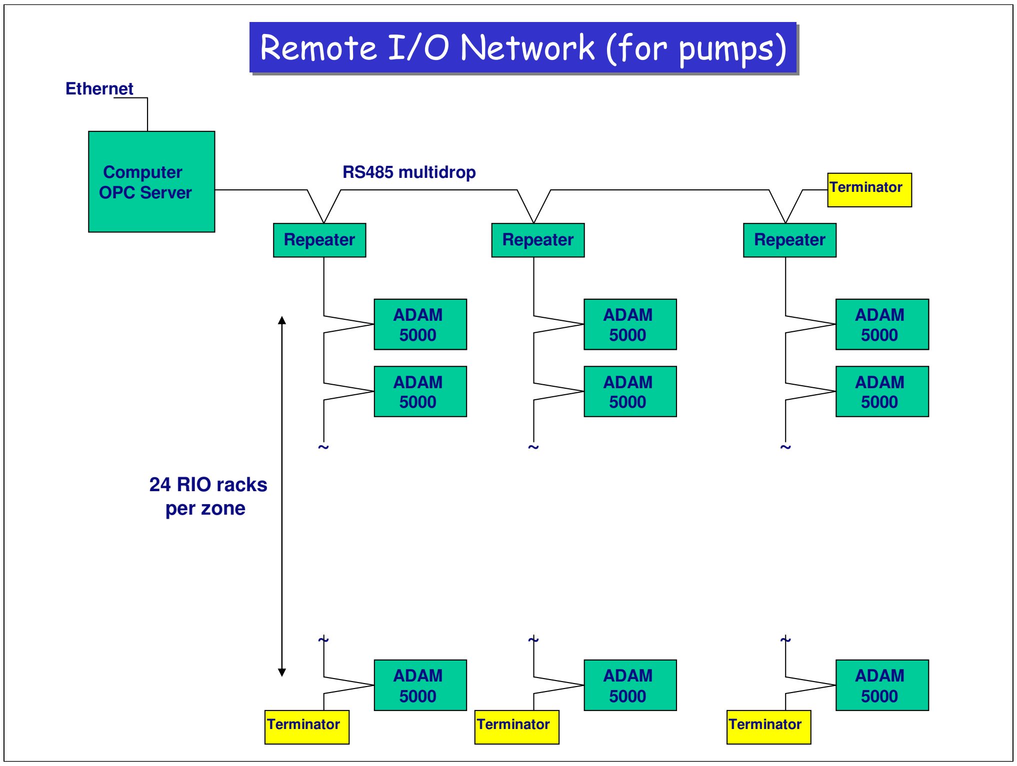
Remote I/O for Pump Units

ADAM 5000 Series from Advantech America looks like a good candidate:



ADAM 5000/485 4 slot rack	$ 350
ADAM 5013 3 channel RTD module	80
ADAM 5080 4 channel counter/freq module	225
ADAM 5080 discrete 8 input / 8 output module	100
subtotal	$ 755
less 20% qty discount	(151)
our price each	$ 604

http://www.advantech.com
Phone: 800 205 7940



RS 485 twisted pair multidrop network would be fast enough and save space in raceways. ADAM series is available with Ethernet but is more expensive, and would require a separate cable for each unit branching from hubs.

Pump Unit Cost Estimate

:

1	Remote I/O Unit (Advantech Adam 5000)	$	600	$	600
1	Pump 1/6 hp	$	200	$	200
1	Motor Starter	$	120	$	120
1	Heat Exchanger (~LytronLL520)	$	200	$	200
1	Fluid Reservoir	$	50	$	50
1	Fluid level switch(float, capacitive, other)	$	80	$	80
2	Temp probes, RTD in welded SS fitting	$	50	$	100
1	Flowmeter (~Proteus 06008BN14)	$	180	$	180
1	24 VDC Power Supply	$	80	$	80
1	enclosure	$	200	$	200
x	Misc pipe, wire, cable	$	100	$	100
40	man-hours assembly:	$	50	$	2000
	Total			$	3910

New Top Loop Cost Estimate

Cost estimate for average loop on top of detector:

14.67	Top(32 tap) manifold assembly	$ 780	$ 11440
1	Pump & Instrumentation Unit	$ 3910	$ 3910
x	Misc pipe, wire, cable	$ 100	$ 100
24	man-hours assembly: mount 14.67 manifold sections make ~234 quick connects mount & connect pump unit & other components install wire duct, field wiring, fill, test etc.	$ 50	$ 1200
	single loop subtotal		$ 16650

Revised estimate using manifold estimate from G Fischer, higher power pump, and 20k ton dimensions.

For 20 kton detector, with 22 blocks of 62 planes, there would be 2 zones with loops 7 manifold sections long, and 1 zone of loops 8 manifold sections long. [(7 +7+8) x2] / 3 = 14.67, average number of manifolds for costing.

Illustrates the significant role of manifold cost.

cost of spacer sections and return pipes ignored

New Side Loop Cost Estimate

Cost estimate for average loop on side of detector:

29.33	**Side(16 tap) manifold assembly**	**$ 580**	**$ 17013**
1	**Pump & Instrumentation Unit**	**$ 3910**	**$ 3910**
x	**Misc pipe, wire, cable**	**$ 100**	**$ 100**
30	**man-hours assembly:**		
	mount 29.33 manifold sections		
	make ~234 quick connects		
	mount & connect pump & other components		
	install wire duct, field wiring, fill, test etc.	**$ 50**	**$ 1500**
	Single loop subtotal =		**$ 21523**

This is for new double length side loop configuration. Cuts number of side loops in half

For 20 kton detector, with 22 blocks of 62 planes, there would be 2 zones with loops 14 manifold sections long, and 1 zone of loops 16 manifold sections long(doubling back). [(14+14++16) x2] / 3 = 29.33, average number of manifolds for costing.

return pipes not needed

cost of spacer sections ignored

Total Cooling Loop Cost Estimate

36	Loops, Detector Top	$ 16650ea	$ 599400
36	Loops, Detector Sides	$ 21523ea	$ 774828
		Grand Total =	$1,374,228

Again, based on 20 KT dimensions.

This estimate does not include slow controls software or integration costs. Also assumes cost of chilled water system from FES is accounted for elsewhere.

Old Loop Cost Estimate

SWAG cost estimate for loops on detector top, side loops a bit lower:

1	Pump 1/25hp bronze cast	$ 150	$ 150
1	Heat Exchanger (~LytronLL520)	$ 200	$ 200
16	Top manifold assembly	$ 830	$ 13280
1	Fluid Reservoir	$ 50	$ 50
1	Fluid level switch(float, capacitive, other)	$ 80	$ 80
2	Temp probes, RTD in welded SS fitting	$ 50	$ 100
1	Flow switch (~Omega FST-211-SPST)	$ 160	$ 160
1	enclosure	$ 200	$ 200
6	Remote I/O channels(2 temp, 1flow, 1 level, 1 pump status, 1 pump control)	$ 200	$ 1200
x	Misc pipe, wire, cable	$ 100	$ 100
24	man-hours assembly: mount 8 manifold sections make 512 quick connects mount & connect pump & other components install wire duct, field wiring, fill, test etc.	$ 50	$ 1200
	Total		$ 16720

Previous estimate with truly WAG manifold cost, 30k ton dimensions

Use Macroflow?

Innovative Research, Inc.
3025 Harbor Lane N, Suite 300
Plymouth, MN 55447, USA
Tel:(763) 519-0105

Macroflow is a CAD tool that is written by Innovative Research in Plymouth, MN.

Company founded by a retired UMN ME professor, Suhas Patankar.

We have made preliminary contact with them last fall. Might be well worth our while to let them model our loop design before we prototype it, and alternate designs if necessary. Full license $5k, but lower cost short term license or fee based consulting also possible.

SuperBrute Brochure

Advantages:

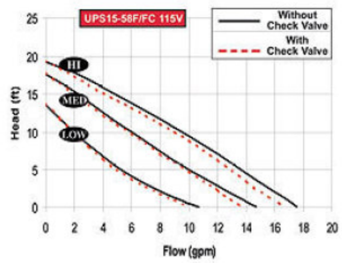
- Removable, integrated check valve does not diminish pump performance
- Eliminates the expense of an inline check valve
- Prevents thermo-siphoning
- Easily match pump performance to system requirements
- 3-year warranty

Technical Data:
Flow Range: 0 - 17 U.S. GPM
Head Range: 0 - 19 Feet
Motor: 2 pole, Single Phase
Max. Fluid Temperature Closed System: 230°F (110°C)
Min. Fluid Temperature for UP15: 36°F (2°C)

Minimum Pressure Temp Requirements:

Competitive Cross Reference

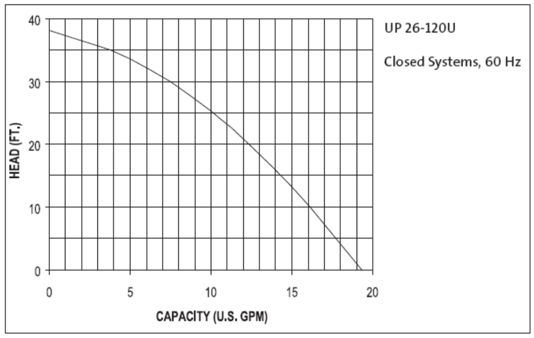
SuperBrute 3-Speed technology replaces the following pumps:	Taco	Bell & Gossett	Armstrong
low speed	005-IFC	NRF-9F/LW	
medium speed	005		
	007-IFC		
high speed	008-IFC	NRF-22	Astro 30
	007		
	008		
	0010-IFC		



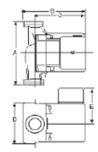
Materias of Construction:

1/4 hp Pump Data

UP 26-120U



Flow range:	0 - 19 U.S. GPM
Head range:	0 - 38 FEET
Motors:	2 Pole, Single Phase
Maximum fluid temperature:	203°F (95°C)
Min. fluid temperature for UP :	32°F (0°C)
Maximum working pressure:	145 PSI

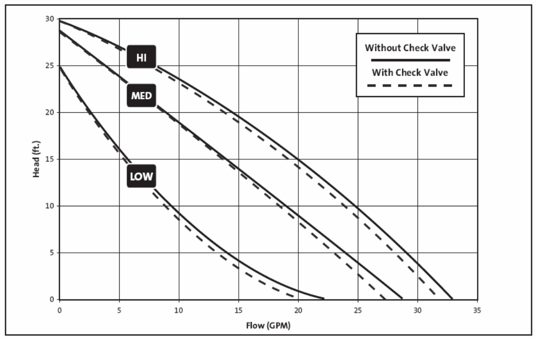


MODEL	VOLTS	AMPS	WATTS	HP	CAPACITOR
UP26-120U	115	2.15	215	1/6	10mF/180V
	230	1.07	220	1/6	2.5mF/380V

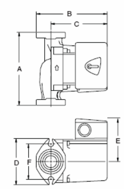
Model Type	A	B	C	D	E	Connection Type and Size	Shipping Wt, (Lbs,)
UP26-120U	7 1/16	5 7/8	5 1/16	4 7/8	3 1/2	GF 125 Union – 1 1/4" NPSM	10 1/2

1/6 hp pump data

UPS 26-99FC/BFC SUPERBRUTE



Flow range:	0 - 34 U.S. GPM
Head range:	0 - 30 FEET
Motors:	2 Pole, Single Phase
Maximum fluid temperature:	230°F (110°C)
Min. fluid temperature:	36°F (2°C)
Maximum working pressure:	145 PSI

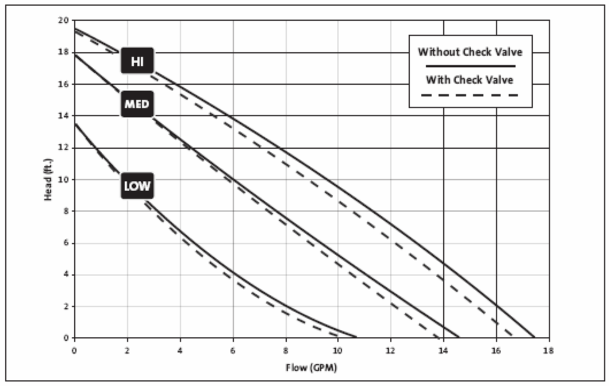


MODEL	VOLTS	AMPS	WATTS	HP	CAPACITOR
115V	Spd. 3	1.8	197	1/6	20mF/180V
	Spd. 2	1.5	179	1/6	20mF/180V
	Spd. 1	1.3	150	1/6	20mF/180V
230V	Spd. 3	0.9	196	1/6	5mF/400V
	Spd. 2	0.8	179	1/6	5mF/400V
	Spd. 1	0.7	150	1/6	5mF/400V

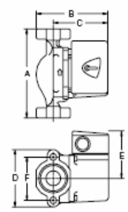
Model Type	A	B	C	D	E	F	Connection Type and Size	Approximate Shipping Wt. (lbs)
UPS26-99FC/BFC	6 1/2	6	4 7/8	3 1/2	3 7/16	3 5/32	GF 15/26 Flange - (2) 1/2" Dia. Bolt Holes	10.3

1/25 hp pump data

UPS 15-58FC/FRC SUPERBRUTE



Flow range:	0 - 17.5 U.S. GPM
Head range:	0 - 19 FEET
Motors:	2 Pole, Single Phase
Maximum fluid temperature:	230°F (110°C)
Min. fluid temperature:	36°F (2°C)
Maximum working pressure:	145 PSI



UPS15-58FC/FRC		AMPS	WATTS	HP	CAPACITOR
115V	Spd. 3	0.75	87	1/25	10mF/180V
	Spd. 2	0.66	80	1/25	10mF/180V
	Spd. 1	0.55	60	1/25	10mF/180V

This 1/25 hp three speed pump